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AN EXPERIMENTAL INVESTIGATION OF THE POSITIVE AFTER-IMAGE IN AUDITION[1]

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Contents

Our problem is to find out if there is a positive auditory after-image, analogous to the positive after-image in vision, and in that case to describe it in attributive terms. If we detect the presence of auditory experience after the stimulus ceases, we must seek to identify this experience as after-image, or memory after-image, or memory image, or whatever it may be.

[1] From the Psychological Laboratory of Cornell University.

Historical

The first experiments upon the after-effect of auditory stimulation appear to have been made by Mayer.[2] The sources of tone were tuning-forks supplemented by resonators. The tones were conducted to the one ear by means of a rubber tube; the other ear was plugged with wax. Between the nipple of the resonator and the free end of the conduction-tube stood a siren disk. When a space between the holes in the disk was before the nipple, the sound waves were blocked; when a hole was before the nipple, the sound passed into the tube at full intensity. As the disk was rotated, short periods of stimulation alternated with equal periods without stimulation. The critical value sought was the length of the interval between tones which would just be bridged, without loss of sensible intensity, by the after-effect, so that the *O* should hear a smooth tone.

Urbantschitsch[3] worked by a similar method. The tones were interrupted by a pendulum, which carried the one end of a conduction-tube to and fro past the limbs of a Y-tube. The tube to *O*'s ear, which completed the conduction system, was connected to the stem of the Y-tube. Unlike Mayer, Urbantschitsch sought to determine the critical interval at which the tones would just fall apart. The aim of the experiments was to measure the full duration of the after-effect, whereas Mayer measured only that part of it which showed no decrease of sensible intensity.

Schaefer[4] criticizes the method of interruptions on the ground that it cannot take separate account of the *Abklingen* and *Anklingen* of the tones employed. Marbe[5] also considers the method inadequate. "An investigation of the facts of *Abklingen* in auditory sensation can not be made . . . by means of successive, periodic stimuli, but only by the more difficult means of isolated auditory stimuli."

Urbantschitsch[6] further studied what he calls "primary" and "secondary" positive auditory after-images. The "primary" after-image is so closely joined to the sensation that there is no perceptible break between the two; the "secondary" after-image follows the sensation only after an interval, and may recur several times, at intervals of varying length. Urbantschitsch's method is so imperfectly reported that it is impossible to undertake a repetition of his experiments. We are told only that three tuning-forks were sounded at four intensities (characterized as "very strong," "strong," "moderately strong," and "weak") for periods of 5 and 15 sec.

Experimental

We employed two sources of tone: Stern variators, with tube-transmission, and vibrating telephone receivers. It may be said at once that the principal difficulty with either source

[2] A. M. Mayer, "Researches in Acoustics," *Amer. Jour. of Science and Arts,* 147, 1894, 1 ff.

[3] V. Urbantschitsch, "Ueber das An- und Abklingen acustischer Empfindungen," *Archiv. für d. ges. Physiol.,* 25, 1881, 323 ff.

[4] K. L. Schaefer, Nagel's *Handb. der Physiol.,* 3, 1905, 507.

[5] K. Marbe, "Akustische Prüfung der Thatsachen des Talbotschen Gesetzes," *Archiv für d. ges. Physiol.,* 100, 1903, 557.

[6] V. Urbantschitsch, *op. cit.;* and "Zur Lehre von der Schallempfindung," *Archiv für d. ges. Physiol.,* 24, 1881, 585 ff.

was to secure a clean cut-off of the stimulus-tone. Our successive arrangements, therefore, represent repeated efforts at improvement in this respct. The experiments were performed in a suite of three rooms. It was necessary to spread the apparatus over a wide space on account of the power of tones to penetrate even heavy stone walls. Accordingly the *O*'s sat in one room, *E* operated the apparatus in another, and a large unoccupied room lay between. Even so we found that the sources of the higher pitches at greatest intensity must be enclosed in soundproof boxes.

Series I

In our first series of experiments the source of tone was the variator. Four pitches were used, 1024, 512, 256, and 128 vs. The variators were blown at three intensities, and for three durations of stimulation. The three intensities were obtained by setting the air-pressure at 15.0, 7.6, and 4.0 mm. of water for the pitch of 1024 vs; at 5.0, 2.6, and 1.6 mm. for 512; at 19.0, 11.6, and 8.0 mm. for 256; and at 8.0, 5.5, and 4.0 mm. for 128. The nozzle of the variator was so adjusted to the mouth of the cylinder that a maximum of intensity should require the lowest possible pressure. We found that the pressures could not be equated, but varied from instrument to instrument, as indicated by the pressure-values just listed. The durations were 5, 15, and 30 sec. read directly from a Pye clock. Since the seconds-hand of this instrument moves over a dial of 11 cm. diameter, the spaces between seconds are broad enough to admit of accurate reading.

A special control enabled us to adjust the air-pressure quickly and accurately. A wooden lever 85 cm. long, screwed to the handle of the rotary valve, swung before a ruled pressure-scale. From one side of the lever and 60 cm. from the valve, two metal arms (2 cm. long and 0.5 cm. broad) extended parallel to each other and at right angles to the edge of the lever. They were 4 cm. apart, and a fine wire was drawn taut from the outer end of the one to the outer end of the other. This wire, parallel to the edge of the lever and to the lines of the scale, lay on the surface of the scale in such wise that the error of parallax was avoided.

The sound-waves were picked up by a funnel of cardboard and reflected into a brass conduction-tube of 1.9 cm. inside diam. and 0.15 cm. thickness. The small end of the funnel fitted snugly over the end of the brass tube; the diameter of the large end was 15.0 cm.; and the length of an element in its surface was 45.0 cm. This slant is that of an old model of Victrola horn, and is approximately the same as the slope of the funnel in Marbe's *Sprachmelodie-Apparat*. When the variator was set in position, its mouth was in line with the axis of the funnel, just not touching the edge.

The brass conduction-tube was 8.76 m. long. It passed through two walls, across the middle room of the suite, and ended in *O*'s room in an iron pipe 2.3 m. long. The iron pipe, which lay horizontally against the wall and at right angles to the brass tube, served as distributor of the tones to the four booths in which the *O*'s sat. Four nipples were tapped into it, and from these four rubber tubes, of 0.6 cm. inside diam., led to four pairs of stethoscopic ear-pieces. The brass tube

entered the iron pipe at its middle, and the nipples were at 36 cm. and 104 cm. right and left. Under these conditions, the intensity at all listening tubes was sensibly the same. The booths in which the *O*'s sat were separated by heavy curtains.

We have described above the valve which controlled the blowing pressure. It was necessary to introduce another valve between the pressure-valve and variator, which should cut off the air suddenly and bring the tone to a sharp ending. The special valve constructed for this purpose somewhat resembled the piston-valve of a cornet. In one position of the piston, the air went straight through the one opening to the variator, while the other opening was closed at the tube in which the piston moved. In the other position, the passage was reversed; the hole which had been open was now closed, and conversely. In this second position, no more air could enter the part of the tube between valve and variator, and the air which was present under full blowing pressure when the valve first closed had two outlets, the one by way of the nozzle of the variator, the other by way of the passage through the valve. Since the latter passage offered the lower resistance, most of the pressure was spent in this direction, and the terminal "whoop" which otherwise was very troublesome to the *O*'s was reduced to the vanishing point. (Unless the air escaping from the tube, in the process of reduction of the pressure within it to atmospheric pressure, can be diverted from its course through the nozzle, the pitch of the tone in dying falls quite perceptibly as the pressure diminishes.) The diam. of the holes through the piston, 0.6 cm., was the same as the inside diam. of the rubber tube carrying the air to the valve; so that the piston need be moved no more than 0.7 cm. to open the one passage and close the other. In the first series of experiments we threw the valve by hand.

As warning signals we used four small 4-volt incandescent lamps placed upon the wall before the *O*'s. The circuits were so arranged that the light could be made to glow at two intensities. The lamps were turned on at the lower intensity at the beginning of the experimental hour, and remained at this intensity throughout, except when they were flashed as signals; at the lower intensity they showed merely a dull red glow. Our object was, by keeping the filament constantly warmed, to increase the sensitivity of the lamp. We needed to have it flash brightly in an instant, an impossible result if the filament were cold at the outset. *E* closed a key to flash the usual "Ready," "Now" signals. When the air was turned on at the valve, the same movement closed a mercury-contact key attached to the piston of the piston-valve, and the lights burned brightly. When the air was cut off, the movement of the piston broke the circuit, and the lights dropped to the lower intensity. This method secured temporal coincidence of the cutting-off of the tone and the dimming of the lamp.

Every *O* had at his hand a key making or breaking the circuit in the recording apparatus. This apparatus consisted of eosin writers adapted to use with ticker paper. They were made of tin; and though different in structure their principle of operation was that of the draughtsman's ruling pen. They wrote from the horizontal position, withstood hard knocks, and did not spill the fluid when tapped rapidly against the paper. When *O*'s key was closed, the tip of the writer was pulled against the paper by an electromagnet, and a line was written representing the length of any after-effect which might be experienced. When *O* was ready for the next tone he tapped the key as a signal to *E*. The writers were so slender that we were able to

write one time-line and four record-lines upon the usual ticker paper 1.8 cm. in width.

The dashes in the time-line were made by a Kronecker interrupter vibrating in tenths of sec. To fix the exact moment at which the tone began, we resorted to another mercury-contact key upon the piston of the piston-valve. When the air was cut off, the circuit was closed, and the time-writer wrote a continuous line; when the piston moved to turn on the air, the circuit was broken, and under power from another circuit the interrupter-point began to write tenths of a sec. The paper was drawn by a motor which ran throughout the experimental hour; but the feed of the paper was controlled by a clutch, and it was drawn past the writer only when needed. With this arrangement there was no lag of the paper; it was drawn immediately at full speed.

Observers. The *O*'s were Mr. R. T. Holland, graduate student and assistant in the department; Miss M. F. Martin, Dr. C. W. Perky, Miss A. H. Sullivan, and Mr. S. Takaki, graduate students majoring in Psychology. Observer P was somewhat more highly practised than the others, but all were experienced *O*'s.

Instructions. "You will hear a tone which will begin when the signal light brightens, and will cease abruptly as the light dims. You are to note whether the tonal sensation continues or recurs after the dimming of the light. If it continues, you are to press the key immediately and release it at its final disappearance. If it recurs, you are to press the key at every appearance and hold it until the disappearance of the recurring sensation. When the experiment is over, you will write a descriptive account of the after-sensation or after-sensations on the blanks provided."

For every pitch there were 9 stimulations presented in the order: strong-short; middle intensity-middle duration; weak-long; strong-middle duration; strong-long; middle intensity-short; middle intensity-long; weak-short; weak-middle duration. This series of 9 stimulations was run off first with the highest pitch, then with the remaining three pitches in descending order. There were thus 36 experiments in a series. Every series was repeated five times, giving a grand total of 180 experiments for every *O* with this first arrangement of apparatus.

Results

Our results showed a considerable number of cases in which the tones "ended abruptly," were "chopped off," with no trace of terminal modification or after-effect. Besides these, however, there were cases described in which the ending of the tone was modified, in quality, in intensity, or in temporal

course. The O's spoke of "slow dying," "prolonged ending," "not abrupt," a "whoop." Never did the modified ending carry sensibly beyond the dimming of the light, or suggest to O the continuation of the sensation in a positive after-image.

Table I is a summary of all modified endings. Unfortunately, we cannot be sure of their interpretation. The slow cooling of the filament in the lamp may have led to error in judgment on the part of the O's. The apparatus could not guarantee that what was heard was the natural ending of a suddenly stopped tone; so that these modified endings may

TABLE I

0	Intensity			Duration			Pitch				Total
	Strong	Medium	Weak	30	15	5	1024	512	256	128	
H	22	18	7	17	14	16	18	14	14	1	47
M	30	27	29	29	32	25	28	20	20	18	86
P	36	29	22	27	30	30	24	23	27	13	87
S	37	32	38	39	38	30	35	34	16	20	107
T	30	25	20	26	26	23	22	19	23	11	75
Total	155	131	116	138	140	124	129	110	100	63	402

in fact have followed the last vibration, and thus may represent an after-effect. Besides this serious defect in the apparatus, our first series of experiments indicated that several minor changes were necessary. Noises in E's room reached the O's through funnel and conduction tube; the purr of the motor which drew the ticker paper had in it a note that was easily mistaken for an after-image; the hand-operated valve was not always thrown with equal speed from the one position to the other; and any echo of the tones in E's room might reach the O's.

Experimental: Series II

We chose the lights as signals because they were silent; but they were not reliable; and we now substituted for them small electromagnets from a player-piano. These magnets are not noisy; and when operated by a weak current, just strong enough to produce a light, quick movement, they did not annoy the O's. To the armature of the magnet we soldered a strip of tin, 4 cm. by 0.5 cm., to serve as signal flag. Every O had a magnet and flag in his booth before him, at the place where the light had been. When the current was off, the flag stood almost vertically; when it was turned on, the flag was pulled quickly down to the horizontal.

In order to operate the piston-valve quickly and at a constant speed at all times, we built two solenoids end to end on a single base. They were mounted at the end of the piston, and an extension of the piston passed through them both. One solenoid pulled the piston to turn the air on, the other pulled it back again to turn the air off. With a sufficient current the shift was almost instantaneous.

We shut out the noises from *E*'s room by placing the variators in a sound-proof box. We cut the funnel down to a smaller size (diam. 10 cm., length 25 cm.) for use inside the box. The whole conduction system was now isolated, though there was still the possibility of echo from the walls of the box. Indeed, we found that there was a faint tone which made its appearance regularly at a short interval after the air was cut off. We satisfied ourselves that this tone was in the apparatus, and was not subjective, by making records of the vibrations. A diaphragm of the Marbe *Sprachmelodie-Apparat* was held firmly against *O*'s end of the conduction tube, and the smoke-rings registered the tone.

To rid ourselves of this source of error, we so hinged one of the sections of brass conduction-tube that the one end of it could be drawn aside. The other end was attached by a heavy rubber tube to the fixed end of the next section of conduction-tube. An electromagnet in series with the solenoid which cut off the air to the variator pulled this swinging section of tubing to one side at the same time that the variator ceased to be blown. In this way the echo was diverted into the middle room of our suite, and the *O*'s could not hear it. We found it very difficult to swing the pipe noiselessly, but we finally hit upon the following arrangement. One end of a thin strip of wood, about 1 m. long, was fastened to the floor with a hinge; the other end carried the swinging end of the conduction-tube. The electromagnet was fastened to a firm support about 30 cm. from the floor. A piece of iron, screwed to the thin strip at this level, was attracted by the magnet, and the pipe was thus drawn aside. The iron was faced with felt; and by this means, supplemented by the elasticity of the strip of wood, the pipe was brought to rest silently in its new position. The supporting wooden strip stood so nearly vertical that it was easily pulled toward the magnet; but it was inclined so far away from the vertical that gravity pulled it back to the first position when the circuit to the magnet was broken. A piece of spring steel, faced with felt where it touched the wooden strip, furnished a silent stop for the pipe when it returned to the position for conduction. The swinging section was 1.82 m. long; with a radius so large, and an outside diam. of the tube of only 2.2 cm., the space between the swinging end and the fixed end of the next section could be about 0.25 mm. The space was adjusted at every experimental hour so that the ends should just not touch. The break in the pipe was 84 cm. from the point at which the brass tube joined the iron pipe in *O*'s room. We felt satisfied that, with a distance so short as this, no residual sound-waves remaining in the conduction system between the *O*'s and the break in the tube could have any effect for audition.

In the light of our first results, it is clear that the warning signal must be very accurately timed. The modification in the ending of the tone was so short that the flag must move in exact coincidence with the last sound-wave. We turned again to the Marbe apparatus. It was set up with two diaphragms and one gas-burner, all in the same gas system. One diaphragm made the tone-rings, the other the ring from the flag. The diaphragm at the flag was brought so near the flag that the first beginning of movement was recorded by the membrane. By this arrangement the effects from the two membranes were superimposed. The record should show a band of regular rings representing the tone, and then an aperiodic ring written by the flag, followed by a band with no rings. By carefully adjusting the contact placed where the swinging section of conduction-tube would close the

circuit to the flags, we were able to secure this kind of record. The heavy ring from the flag showed as the last ring in the series, and it stood at the proper distance from the last ring but one to be in coincidence with the last tone-ring. To be sure, the record did not indicate whether the heavy ring was the result of a summation of two rings; but it did show that the flag was not more than one vibration out of step with the tone (256 vs.). Still, however, there was the possibility that the stroke of the flag blotted out the tone-rings; tone might be present, but unrecorded. We put this possibility to the test by allowing the flag to make its ring without cutting off the tone. We found that the tone waves were just as distinct in the record after the stroke of the flag as they were before. The disturbance in the flame set up by the flag did not blot out the effect of the tone, but gave a superposed effect.

With these improvements in the apparatus we were ready for the next set of experiments.

Observers. The *O*'s were H, M, S, T of the previous group.

Instructions. " You will hear a tone which will begin when the signal flag falls, and will continue for a varying period of time. About a second before the tone ends, the flag will fall as a warning signal that the tone is about to end. Just at the instant that the tone ceases abruptly, the flag will fall again. You are to note whether the tonal sensation continues or recurs after the flag falls. If it continues, you are to press the key immediately and release it at the final disappearance of the after-sensation. If it reappears, you are to press the key at every appearance and hold it until the disappearance of the recurring sensation. When the experiment is over, write a descriptive account of the after-sensation or after-sensations on the blanks provided."

The experiments in this series were conducted with the same tones as before, in the same order. Except for the changes in the apparatus, already described, and for the warning signal given during the course of the tone, the method is the same as in the first set of experiments.

Results

The distribution of the modified endings is shown in Table II. The decrease in number between Series I and Series II

TABLE II

0	Intensity			Duration			Pitch				Total
	Strong	Medium	Weak	30	15	5	1024	512	256	128	
H	5	1	0	2	3	1	2	0	4	0	6
S	35	28	26	36	32	21	32	30	18	9	89
T	6	2	2	7	3	0	4	2	0	4	10
M		(none)			(none)			(none)			
Total	46	31	28	45	38	22	38	32	22	13	105

seemed to indicate that further refinements might lead to their complete elimination. We, therefore made additional efforts to refine our technique.

Experimental: Series III

So long as the tones were stopped by cutting off the air, there was escape of the air under pressure between the nozzle of the variator and the piston-valve. An unknown part of this air must certainly escape by way of the nozzle; and its escape, if audible, might lead to *O*'s reports of modified endings.

Only after we had discovered how difficult it is to avoid the influence of the diminishing air pressure, did we turn to the rather obvious plan of allowing the variator to blow continuously, while we broke the path of conduction in order to obtain the periods of silence between stimulations. We accomplished this by swinging more sections of the conduction-tube. The section at the sound-proof box was pivoted at the middle to allow the ends to move up and down. The fulcrum was a wad of cotton, packed rather tightly around the pipe in the hole in the stone wall through which it passed. The next section was joined to this lever of conduction-tube and to the third section in the line by rubber tubing fitted over the ends of the pipe. When the end of the pipe in *E*'s room was thrown down, the end in the middle room went up, carrying with it the end of the second section. This movement produced a break in the line at the box, but preserved the continuity in the next room. At the other side of the room was the section adjusted to swing in the previous set of experiments. The swinging end was now supported by a wire and pulley, so that it could be drawn up and dropped down. The means of obtaining simultaneous and equal movement at both breaks in the conduction system was very simple. The wire just mentioned extended across the middle room; its ends dropped vertically down from the pulleys and were fastened to the conduction-tube, the one end to the end of the lever section, the other to the free end of the swinging section. When the end of the lever at the variators went down, the end in the next room went up by an equal amount, since the fulcrum was in the middle. This upward movement allowed the wire to roll over the pulleys, and the end across the room dropped by an amount equal to the movement of either end of the lever section. The displacement thus secured was about 5 cm. The pull upon the pipe was exerted by means of a solenoid fastened to the floor in *E*'s room. A cord tied to the end of the lever-section supported the core at a good pulling distance above the center of the solenoid. With a strong current, the displacement was sudden and free from noise. We found it necessary, however, to sew the core of the solenoid into a close fitting bag, in order to secure silent action of the core within the coil.

It is obvious that the shape of the ends of the conduction-tube at the break could not be circular. The diminishing amount of area for conduction as the ends became separated might be responsible for an observable decrease in intensity of the tone. The ends of the tube, except for a slit of 1.8 cm. by 0.3 cm., were accordingly plugged with sealing wax. The long dimension of the slits was horizontal, so that a quick movement of the end of the pipe downward brought them wide apart, too rapidly for any sensible decrease in intensity. We tried at first to use four of these slits, but found that they reduced

the intensity; two at the sound-proof box were sufficient. The circuit driving the signal flag was again closed by the swinging pipe.

We found that the two high tones could be heard three rooms away, even though the variators were in a box with very heavy double walls, if they were sounded at more than our intermediate intensity. We accordingly decreased the blowing pressure to 2, 4, 7.6 cm. of water for the tone of 1024 vs.; and to 0.9, 1.6, and 2.6 cm. of water for that of 512 vs. The two breaks in the conduction-tube weakened the low variator tones beyond usable limits. In their stead we used tuning-forks (with resonators) of 256 and 128 vs. The resistance in the circuit was such that at 10 v. we obtained satisfactory driving power for the forks at 1, 2, and 3 amps. for 256 vs.; and at 2, 3, and 5 amps. for 128 vs.

Results

The results from this series of experiments are shown in Table III. We reserve comment upon them until later.

TABLE III

0	Intensity			Duration			Pitch				Total
	Strong	Medium	Weak	30	15	5	1024	512	256	128	
S	30	26	20	25	27	24	30	33	7	6	76
T	1	3	4	3	3	2	3	3	1	1	8
Total	31	29	24	28	30	26	33	36	8	7	84

Experimental: Series IV

The apparatus just described was satisfactory except for the fact that the tones were weak. As it stood we could be reasonably certain that the *O*'s heard the natural ending of a tone, the sensible process of transition from tone to silence. The noise incident upon swinging the pipes was, it is true, barely noticeable just after the ending of the tone was heard, and a very faint after-image might have been lost. But the main fault lay with the intensity of the stimuli themselves. We required a source which should have fairly intense tones, and which should be completely silent in the period following the cessation. After a good deal of cut-and-try experimenting, we had recourse to telephone receivers.

The instrument was the ordinary variety of receiver of 75 ohms resistance. It was actuated by a Petzold double induction coil, with a current of 2 amp. at 6 v. through the two primaries connected in series. The vibration frequency in the receivers was determined by the number of interruptions in the primary, and not by a separate source of sound. By this method we avoided the complications which a transmitter would have introduced. The interrupters were tuning-forks of 435, 350, 256, and 100 vs. We were unable to drive the forks satisfactorily by the same current which passed through the primaries of the coil; by means of an extra pair of contacts put upon the forks, we passed two separate currents through them, the one driving the fork, the other leading to the induction coil. A condenser connected across the point of interruption in the circuit to the coil kept down the sparks at the interrupter, and gave a tone free from the usual click and buzz of receivers.

The line across which the receivers were connected derived its power from the secondary coils connected in series. A special switch with tion. After a good deal of cut-and-try experimenting, we had re-breaking both sides of the line at once. When one side alone was broken, the receivers sounded faintly; and they could be made silent only by interrupting both sides of the line together. This same switch also carried contacts controlling the signal flags. When the path to the receivers was broken, the circuit to the flags was made, just far enough in advance to counteract the slight lag in the flags.

The three intensities of stimulation were obtained by setting the secondary coils both at 0; the one at 14, the other at 2; and both at 14. There was no further change in the experimental procedure.

Results

Table IV contains a summary of modified endings from Series IV of 360 observations for every *O*.

TABLE IV

0	Intensity			Duration			Pitch				Total
	Strong	Medium	Weak	30	15	5	1024	512	256	128	
H	120	120	0	80	80	80	60	60	60	60	240
S	119	120	113	120	118	114	90	89	87	86	352
T	6	2	1	2	3	4	1	0	4	4	9
Total	245	242	114	202	201	198	151	149	151	150	601

Significance of Results

So far as concerns a positive after-image, analogous to the positive after-image in vision, we have nothing to report. In a total of 3,780 observations, the results have been flatly negative. But our 'modified' endings are positive results; and as they have been ineradicable, we are obliged to discuss them.

The instructions laid emphasis upon the positive after-effects of our stimuli; and the different *O*'s took different attitudes toward the endings of the tones. In Series I and IV, H reported the modified endings frequently; in Series II, he was especially attentive to after-effects, and only the more pronounced of the modified endings were reported; in Series III, he made the general statement that he could hear a " ylup," if he made an effort to hear it, coincident with the drop of the flag. Throughout the series he took the instructions literally, and reported " Nothing " for the after-effect of every stimulus. M never reported modified endings after Series I, and like H never heard an after-effect. T reported modified endings very infrequently after Series I, but he never totally ignored them. S failed always to hear after-effects, but she persistently gave her attention to modified endings.

An examination of the totals in Tables I to IV shows that for every series the frequency of the report of modified endings is directly proportional to the degree of intensity of stimulus. Even in Series III, where the strongest stimulus was rather weak, the rule holds in some measure. The influence of duration is less regular; but there are always fewer modified endings reported at 5 sec. than at 15 and 30 sec. In the case of pitch, the tables may be misleading. In Series I and II, decrease in frequency of modified endings parallels a fall in pitch; but the high tones were intense and the low were weak; so that what might be taken for an effect of pitch is in fact an effect of intensity. We feel assured, from the results in Series III and IV, that this interpretation is correct. In both these series all pitches were of nearly equal intensity, and the distribution of modified endings is also nearly equal for all pitches. The contradiction in Table III is only apparent. It was very difficult to keep the tuning-forks of 256 and 128 vs. vibrating at low voltages, and for this reason we gave only one series with each. At higher voltages the forks had so great an amplitude of vibration that they struck the core of the electromagnet; for this reason it was impossible to grade the intensities from a higher maximum.

Throughout the earlier series, we regarded the modified ending as due to a fault in technique. We believed that refinement of apparatus would remove it. The agreement between number of modified endings and intensity of stimulus supported this opinion; but the influence of duration was against it. In order to explain the effect of duration, we searched the results to find what terms were used in describing the modified ending. Many references to it were not descriptions, but characterizations like "swoop," "whoop," "sigh," "groan," etc. In Series III, H and S agreed that the difference between the tone and its ending was, in part, one of 'vocality,' which changed as the tone went off. S further described the ending as having "less body than the tone;" it "disappeared out in space," "decreased in volume," "thinned out," "lost quality," etc. We have set down the attributive conditions of stimulus under which such descriptive terms were used in Table V. The results are all taken from Series III, since it is in this series only that the *O*'s maintained a constantly descriptive attitude.

The uniform distribution for duration shows that the modified ending is not dependent upon differences in that attribute of stimulus.

TABLE V

	Intensity			
O	Strong		Medium	Weak
H	120		120	0
S	37		41	43
	Duration			
O	30		15	5
H	80		80	80
S	40		41	40
	Pitch			
O	435	350	256	100
H	60	60	60	60
S	33	42	26	20

In the same group of experiments, certain terms indicative of judgments of intensity, like "pronounced swoop" and "less ŭh," were used. Their distribution is shown in Table VI.

TABLE VI

	Intensity			
O	Strong		Medium	Weak
H	120		120	0
S	10		5	3
	Duration			
O	30		15	5
H	80		80	80′
S	6		6	6
	Pitch			
O	435	350	256	100
H	60	60	60	60
S	10	2	1	5

The extreme regularity of H's results is due to a 'set' for intensity. He reported only upon the relative intensity of the modified endings, which he found to be well above the limen. The figures show again that the modified endings are independent of duration. In Series I, where S frequently gave judgments of length of modified ending, the same result was found: the modified ending was short for all durations of stimulus.

It will be remembered that in every series every degree of intensity was given once with every duration of stimulus. In Series III, we counted the number of times that S used the same term to describe the modified ending for all three durations in a series or for all three intensities. The number of cases is shown in Table VII.

TABLE VII

INTENSITY

Strong	Medium	Weak	Total
12	8	1	21

DURATION

30	15	5	Total
1	2	2	5

PITCH

435	350	256	100
9	6	2	9

It is evident that duration does not markedly affect the modified ending, seeing that for 12 of the 15 times that the strong stimulus was given *O* is able to call the effect by the same name in spite of the 3 different durations of stimulus. The single case recorded in column 3 is very misleading in that 7 of the 12 weak stimuli were negative, *i.e.,* ended abruptly for sensation, leaving only 5 times that a single term could be used. The table shows that duration had a slight influence in determining the descriptive term; but it is only about one quarter as effective as intensity. The 7 negative cases were distributed, 5 to the short, and 2 to the intermediate duration.

In Tables I to IV, difference of duration appears to be effective in determining the number of reports of modified ending, and may, therefore, be a factor in determining their existence or non-existence. In Tables V to VII, duration does not modify the character of modified endings. Our experiments offered the suggestion that pressure in the ears[7] may have been of importance in forcing attention to the modified ending. T reported pressure or deafness following the stimulus under conditions which are shown in Table VIII.

[7] On the perception of silence, see E. B. Titchener, "A Further Word on Black," *Jour. of Philos. Psychol. and Scient. Methods,* 13, 1916, 649 ff.

These results are all taken from Series IV, in which the stimuli were sufficiently strong to make pressure and deafness moderately conspicuous. We conclude from them that both intensity and duration co-operate to bring about a state called sometimes deafness, sometimes pressure. The only time that a weak stimulus produced pressure was when its duration was 30 sec. Here, then, is an effect of duration which may be responsible for its otherwise unexplained influence upon the frequency of report of modified endings. Through it, only those modified endings will be reported which force themselves to the focus of attention. Our instructions, however, tended to direct attention to the period following the ending of the tone. Hence we should expect a report of pronounced or conspicuous endings, but of no others.

TABLE VIII

INTENSITY

Strong	Medium	Weak	
19	18	1	Pressure
4	7	0	Deafness
23	25	1	Total

DURATION

30	15	5	
18	12	8	Pressure
6	2	3	Deafness
24	14	11	Total

PITCH

435	350	256	100	
19	4	9	6	Pressure
4	3	4	0	Deafness
23	7	13	6	Total

In order to substantiate this explanation, it becomes necessary to show, by a special direction of attention, that modified endings are, in reality, always present. H had already said that he could hear them with every stimulus, if he tried. Prof. H. P. Weld (W), and Dr. L. B. Hoisington (Ho.), members of the department and highly experienced *O*'s, had previously been called in for supplementary observations following Series III. At first, they reported modified endings, but when they assumed a passive attitude toward them, and directed their attention to the silence following the end of the tone, the number of modified endings observed became fewer. Their reports indicated, nevertheless, a possibility that all endings of tone are modified.

To put the matter to the test, we made a few experiments, with Dr. K. M. Dallenbach, instructor in the department, H, Ho, M, T, and B (the writer) as *O*'s.

Experimental: Series V

The stem of the Y-tube at the ear-pieces was held in the left hand; and the end of the rubber tube, which previously had been joined to the Y-tube, was held in the right. Both free ends were brought together, just not touching, for stimulation, and were suddenly drawn apart to remove the stimulus tone. The movement was made in all possible directions, with equal effect upon the auditory experience; and the thumb held against the end of the rubber tube to cut off the tone had no different result from that noted with movement of the tube. These movements provided a soundless means of discontinuing stimulation. *O* was asked, first, to direct his attention to the change in the character of the tone just as it ended, and to report whether it could always be heard; secondly, to turn his attention to the period of silence following the tone, and to report, from stimulation to stimulation, whether the silence seemed more or less distinct from time to time; and thirdly, to report the times when the modified ending especially attracted attention. Stimulations were given for 5, 15, and 30 sec.

Results

Every *O* was able to hear a modified ending of every stimulation, if attention were directed upon it, even with weak tones carried almost to the limen. Every *O* found that the stimulus of 5 sec. was incapable of producing any but the faintest pressure which is characteristic of perceiving silence. Durations of 15 and 30 sec. definitely produced the pressure; but the *O*'s did not agree whether 30 or 15 sec. produced the greater pressure. Every *O* found also that the modified ending was not insistent after the 5 sec. stimulation, but that it stood out very conspicuously from stimulations of 15 and 30 sec. In B's experience the heaviness of the deeper silence from long stimulation worked, as if by contrast, to make the modified endings stand out more vividly without necessarily becoming more intense. It seemed to be the 'contrast' between silence and modified ending which grew more intense as the stimulus-time was lengthened. Since the pressure is cumulative with the product of intensity and duration of stimulus; and since the intensity of the modified ending seems to depend upon intensity of stimulus; we conclude that the enhanced 'contrast' effect comes by way of increased pressure.

This, then, seems to be the explanation of the apparently contradictory results. The modified ending varies in intensity directly with intensity of stimulus, and is always present. When the *O*'s report abrupt endings, or fail to report the end-

ing at all, their direction of attention to the period of silence is complete; and no endings, except the most vivid, come to their notice. Long stimulations enhance the contrast-effect between tone and silence, and increase the number of times that *O* hears the modified ending; they thus give the impression that the longer the stimulus-time, the more frequent is the modified ending.

Nature of the Modified Ending

It is tempting to regard the modified ending as 'subjective' in nature, and to identify it with the *Abklingen*[8] or 'drop' of auditory sensation which Mayer and others have attempted to measure. This view is supported by the facts that the modified ending varies directly with intensity of stimulus, and that it shows always a thinning-out or reduction of the 'body' of the tonal complex. While, however, we have no wish to dispute the presence of an *Abklingen,* we are nevertheless of the opinion that, in our experiments, this subjective factor was outweighed by objective changes.

In the first place, we mistrust the results from the telephones. So long as the tone is stopped by taking away the driving power of the diaphragm, there is a source of error remaining: the diaphragm must come to rest from the position in which it happens to be when the current is cut off, and this return is definitely audible. Our arrangement with induction coil and condenser served to eliminate the noisy click natural to the instrument at the moment when it ceases to be under the influence of the electromagnet; but it is evident that the very fact of vibration still necessitates a return to a state of equilibrium.

For a similar reason, the results from the variators are not free from objection. When the variator ceases to blow, we have no means of knowing through what stages the physical stimulus passes in coming to rest. At one moment the air is in motion, and a moment later it comes to rest. Our modified endings may depend in part upon objective change in the sound waves. When the path of conduction is broken by pulling the conduction-tube aside, eddy-curents must be set up around the ends of the tubes; and these, though not audible at low intensities, may change the character of the stronger tones as they end.

[8] For *Abklingen* in general see C. Stumpf, *Tonpsychologie,* 1883-90, references in index: K. L. Schaefer, Nagel's *Handb. der Physiol.,* iii., 1905, 504 ff.

There are, indeed, positive indications that the modified ending is in part objective. (1) The results from Series I-III differ widely with respect to the number of times the pitch changed in any direction. A summary is given in Table IX.

TABLE IX

	Series		
	I	II	III
Pitch rises	6	25	48
" the same	48	15	23
" falls	11	7	5
Total	65	47	76

In Series I, the vibration in the air spent itself normally. In Series II, when the pipe was drawn aside, the path of conduction was interrupted; and eddy-currents at the break may have changed the character of the ending of the tone. The ends of the tube were not plugged; and even though the pipe moved quickly, a certain brief time was required for the movement. In Series III, the ends were plugged, and the movement of the pipe was quicker than in Series II. The eddy-currents would be more intense, owing to the greater speed with which the pipe moved and to the narrowed opening in the pipe. Table IX shows that the increase in the number of judgments of higher pitch, and the decrease in the number of lower pitch, are correlated with the suddenness of the ending of the tone and the violence of the movement of the pipe. (2) We made a few experiments as a check upon the implication of Table IX by the method of pulling the rubber tube away from the stem of the Y-tube at the ear-pieces. When the end of the rubber tube vibrates rapidly before the end of the Y-tube, the movement produces a distinct thud or noisy puff. If the movement be made sufficiently violent, the noise covers up the tone. B, H, Ho, M, and T all reported that the modified ending was most intense, at any intensity of stimulus, when the rubber tube vibrated 4 to 6 times per sec. This result proves that long stimulation does not add to the intensity of the modified ending, but that rate of vibration does, probably from the increase in energy of the stimulus due to interference of air-waves at the ends of the tubes. (3) B and Ho made a number of observations to determine the pitch of the modified ending, and found that it is dependent upon the rate of movement of the end of the tube. A quick movement gives an "oop" higher in pitch than the tone; and a slower movement gives the same kind of sound, but its pitch is lower, and it is softer and has greater volume. Certain

rates of movement give a pitch that is equal to that of the generator. Both forks and variators were used as stimuli. If these observations, made under loose experimental conditions with hand-control of the speed of movement, may be trusted, it is possible that we have an explanation of the results in Table IX; for the judgment of pitch of the modified ending is correlated with the objective suddenness of the movement which interrupted the tones. The observations also furnish additional evidence that the modified ending may be objective;[9] and that, if a means of interrupting tones could be found which did not affect the air in the path of conduction, it might in so far be eliminated. It may, however, be impossible to deprive a tone of its normal means of propagation, the air, without at the same time setting up disturbances in the air.

Such results as ours call for further experiments conducted under the best possible conditions. As our problem was to demonstrate the presence or absence of an auditory positive after-image, the modified endings are incidental to our purpose; and it is unnecessary that we should make a more complete investigation of the conditions upon which they depend. Since, however, their occurence, in so far as it represents an objective disturbance of stimulus at cessation, might give ground for the objection that a possible faint after-image has been covered up and overborne, and thus has escaped the notice of our *O*'s, we have made some further experiments with tones of greater intensity and longer duration.

Experimental: Complex Tones

In order to extend our results to other kinds of stimuli and to long stimulation-times, we conducted a group of experiments with more complex tones. In some experiments the original stimulation-times were used, and in others the time was extended to 5 and 15 min. The tones were *C′* and *C″* from organ pipes of metal; *C* and *C′* from organ pipes of wood; and tones number 2, 4, 6, 8, and 10 from an Appunn reedbox of the overtones of a fundamental of 64 vs.

Our *O*'s in this group were Miss E. C. Comstock (C), graduate student in psychology; Mr. F. L. Dimmick (D), assistant in the department; H, Ho, M, S, T; Mrs. A. K. Whitchurch (Wh), graduate student in psychology; and a class of 7 students in the advanced laboratory course.

[9] It was noticeable from the very first that *O*'s who were observing in the same group did not by any means necessarily report in the same way upon the same stimuli. We have already shown that they varied in their attitude, attending sometimes to the tone's ending and sometimes to the period immediately following. The objective or partially objective character of the modified ending is, therefore, not put in question by the variety of report. Moreover, as we have also shown above, prescribed direction of attention led to uniformity of report.

All tones were blown at full intensity, at the different durations. The *O*'s sat where they could see the *E*'s hand move as the tone was cut off. This movement replaced the signal flag of previous experiments. In all, 448 observations were made. Of these 11 were with 15 min., and 7 with 5 min. stimulation.

Results

Not an after-image was reported; but our practised *O*'s heard modified endings, and felt pressure in the ear from long stimulation.

Our regular experiments had indicated that pressure in the ears made its appearance in place of an after-image, and we wanted striking evidence that this indication was true. If naïve *O*'s could be brought to sense the pressure, without practice, this result would be good evidence of its fundamental nature. Accordingly, our unpractised *O*'s were instructed to describe any after-effect of stimulation that might appear. They were then given number 2 on the reedbox as stimulus for 15 min. All of the group, except one who misunderstood the instruction, reported vivid, throbbing pressure which lasted from 5 to 10 min. after stimulation. Nothing was heard. One *O* remarked that there was no after-image, unless the throbbing were a negative after-image; and added that in this condition the ears "felt very sensitive to noise." If 15 min. of stimulation resulted in so perceptible a pressure, it may be supposed that the naïve *O*'s who were able to report it were also capable of perceiving any tonal after-effect, and that their failure to perceive tone is further evidence that no auditory after-image exists. The case of heightened sensitivity to noise may help to explain why, in the regular series of experiments, long stimuli led to more frequent report of modified endings.

Auditory Recurrent Images

For T, the tone frequently recurred after stimulation. S reported only a single recurrence, the other *O*'s none. The attributive correlates of T's recurrences are given in Table X.

The recurrences were generally 1 to 2 sec. in length, but sometimes were as long as 10 sec. More than a single recurrence was not reported after the sources of tone had been placed in sound-proof boxes. There were numerous 'recurrences,' as many as seven, when the purr of the motor could be heard through the conduction-tube. These recurrences are, of course, not trustworthy. As a rule, the recurrent tone had the same pitch as the stimulus; but it was sometimes one or two octaves above or below. Localization was generally

in the head, though sometimes recurrences were unlocalized. B found that, after serving as *E* for one or two hours, the recurrent tone came as an addition to any faint continuous objective sound, but that in a quiet room no recurrent image could be heard. Our recurrent images obviously resemble the "secondary" after-sensations of Urbantschitsch.

TABLE X

	Intensity			Duration			Pitch			
Series	Str.	Med.	Wk.	30	15	5	1024	512	256	128
I	10	11	3	8	9	7	1	8	11	4
II	0	1	1	2	0	0	0	1	0	1
III	8	3	0	3	5	3	5	3	0	3
							435	350	256	100
IV	5	1	1	4	2	1	2	1	4	0
Total	23	16	5	17	16	11				

In Tables III and IV, T's results are often not in agreement with those of the other *O*'s; but it will now be seen that the disagreement is due to the number of recurrences at higher and middle intensities, or in long and middle durations. The unequal distribution for pitch in Table X may be due, in part, to the influence of the register of T's voice; the recurrences are most frequent within his singing range.

Conclusions

1. There is no positive after-image of tone, analogous to the positive after-image of vision.
2. The 'modified ending' of tones, which we have been unable to eliminate, is probably a compound effect, due in part to tonal *Abklingen,* in larger part to the objective conditions of our experimental arrangement.
3. Intensity of modified ending is dependent upon intensity of stimulus; its vividness or insistence upon pressure in the ear, which increases with intensity and duration of stimulation.
4. It is impossible from our experience to say which of our two sources of tone, the variators with air conduction or telephone receivers, is to be preferred. The variator tones were relatively weak; when they are cut off, slight noise accompanies the swinging of the conduction-tube; if the conduction-tube remains unbroken, echo is a source of error. They furnish, however, an almost purely tonal *Abklingen.* The telephone receivers give tones approximately equal in intensity at all pitches; in the period when the after-image is expected to appear, they are absolutely noiseless; there is no difficulty from echo; but the *Abklingen* is very impure, owing to an admixture of noise from the diaphragm.